v_n measurements with forward rapidity Φ_n in 200GeV Au+Au collisions at RHIC-PHENIX

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Abstract. Higher order event anisotropy v_n have been measured at mid-rapidity with respect to the same order event plane Φ_n defined at the forward rapidity in 200GeV Au+Au collisions at RHIC-PHENIX experiment. Correlation between higher order event planes at different rapidity indicates the initial geometrical fluctuation is the dominant source of the higher order event anisotropy. Hydro-dynamic calculation seems to describe the measurements.

1. Higher order reaction plane correlation

The event anisotropy has been known to give specific rapidity dependence, symmetric and anti-symmetric for even and odd harmonics, respectively, when considering two black disk-like collisions with infinite number of participants in case of symmetric heavy ion collisions. It has also been suggested that the initial geometrical fluctuation of finite number of participant would give rapidity symmetric dependence even for odd harmonics [1]. In order to answer this question, whether which of the observed correlation is stronger between rapidity symmetric and anti-symmetric contributions, the higher order reaction planes are determined with various forward detectors, RXN: reaction plane detector ($|\eta| = 1.0\sim2.8$), MPC: muon piston calorimeter ($|\eta| = 3.1\sim3.7$), BBC: beam-beam counter ($|\eta| = 3.1\sim3.9$) and ZDC: zero degree calorimeter ($|\eta| > 6.5$).

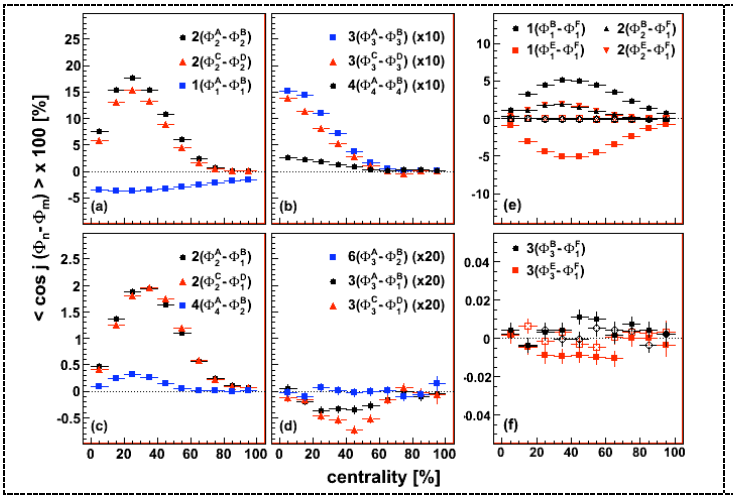

Figure 1. Various higher order event plane correlations between different rapidity are shown as a function of centrality. The choice of event planes are indicated as A:RXN$^{(+)}$, B:BBC$^{(-)}$, C:MPC$^{(+)}$, D:MPC$^{(-)}$, E:BBC$^{(+)}$ and F:ZDC$^{(+/-)}$, where (+) and (-) are for the positive and negative rapidity, (+/-) means combined event plane with flipping sign of (-). See details in the text.

Figure 1 shows the various higher order event plane correlations between different rapidity slices. The panel (a) and (b) show the same order event plane, where the 2nd order correlation is the largest, but the correlation between 3rd order harmonics is quite significant with a large rapidity gap. This is an indication of initial geometrical fluctuation is a dominant source of Φ_3 correlation. The panel (c) and (d) show the cross harmonics correlation, where the correlation between 1st and 2nd as well as 2nd and 4th order have been known to show a significant signal from the v_1, v_2 and v_4 correlation. However, 1st and 3rd order shows a slight negative correlation, which could be an indication of the rapidity anti-symmetric v_3 contribution, although the magnitude of the correlation is about 50 times smaller than the 3rd order correlation. The 2nd and 3rd order shows invisible correlation within the current statistics. The panel (e) and (f) show the correlation of Φ_n at forward region with respect to the Φ_1 at the spectator region. The rapidity anti-symmetric v_1 and symmetric v_2 signals are clearly seen, the rapidity anti-symmetric v_3 signal is weak but observed to have the same sign of v_1, which is known to be negative for pion dominating participant region. Figure 2 shows the higher order event plane resolutions and observed azimuthal distributions.

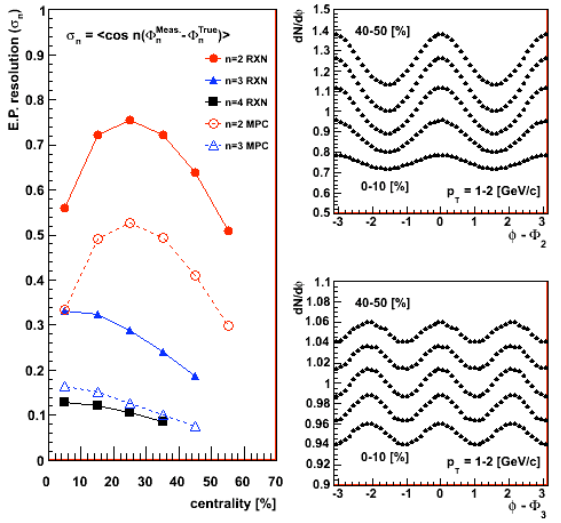

Figure 2. The extracted event plane resolution as a function of centrality is shown in the left panel. The solid symbols are resolutions with RXN, the open symbols are with MPC. The top- and bottom-right panels show measured azimuthal distribution with respect to the 2nd and 3rd order event planes, respectively, for 5 different centrality selections.

2. Two particle correlations with small and larger eta gaps

Two particle azimuthal correlation analysis methods have been used to extract the jet property, suppression and modification as well as event anisotropy. The recent hot topics on the jet correlation analysis have been the "ridge-like" near-side long-range eta correlation and "mach-cone-like" away-side double-peak correlation. It has been suggested that the both of them would have strong relation with v_3 signal, which seems to be dominant effect of initial geometrical fluctuation. The figure 3 and 4 show the comparison of two particle azimuthal correlation functions with large and small eta gaps. The 4 panels in figure 3 are inclusive photon and hadron azimuthal correlation functions measured within the central arm acceptance $|\eta|<0.35$ with varying the eta gap cuts. The 4 panels in figure 4 show the azimuthal correlation functions between central ($|\eta|<0.35$) and forward detectors, the left with RXN ($|\eta|$ = 1.0~2.8) and the right with MPC ($|\eta|$ = 3.1~3.7), while the top shows the fitting and subtraction including the first two harmonics to demonstrate and visualize the significant 3rd order harmonics in the correlation function. The bottom panels include the fitting and subtraction upto the 4th harmonics. This two particle correlation method also provides event anisotropy measurements that can be compared with event plane method.

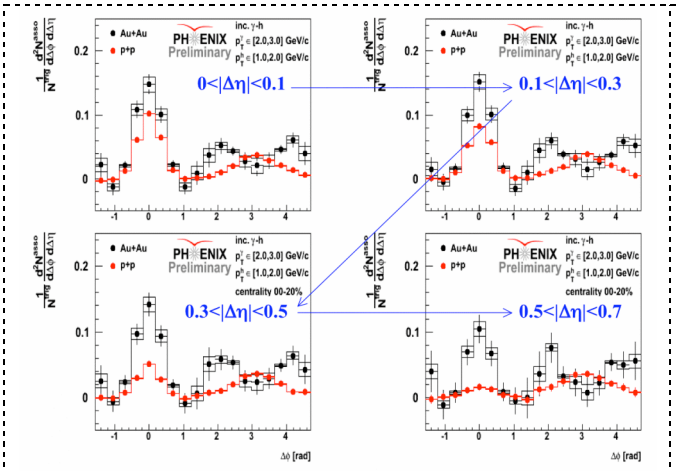

Figure 3. Correlation function between inclusive photon and hadron within the central arm (|η|<0.35), which is v_2 subtracted inclusive photon triggered jet associated hadron Δϕ distribution.

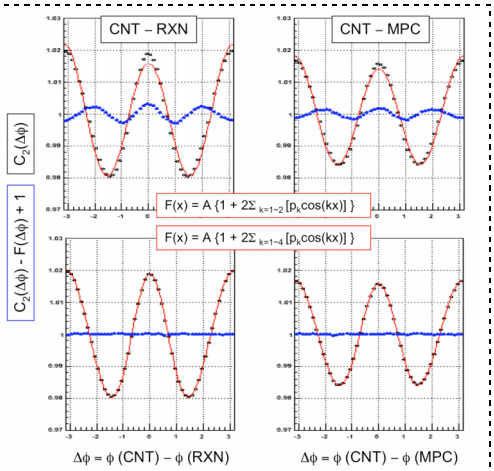

Figure 4. Correlation function between central (|η|<0.35) and forward RXN (|η| = 1.0~2.8) or MPC (|η| = 3.1~3.7).

3. Higher order event anisotropy

Figure 5 shows the measured higher order event anisotropy with respect to the higher order event plane defined at RXN (|η| = 1.0~2.8) as a function of p_T for different centrality selections [2]. The different order harmonics show similar p_T dependence. The magnitude of higher moments v_3 and v_4 are significant especially for the central collisions. Compared with the strong centrality dependence seen in v_2, a very weak centrality dependence of v_3 is observed. The $v_4\{\Phi_4\}$ is found to be about 2 times larger than the previously measured $v_4\{\Phi_2\}$, which is mainly from the overlapped geometry, while $v_4\{\Phi_4\}$ would have an additional contribution from the fluctuation.

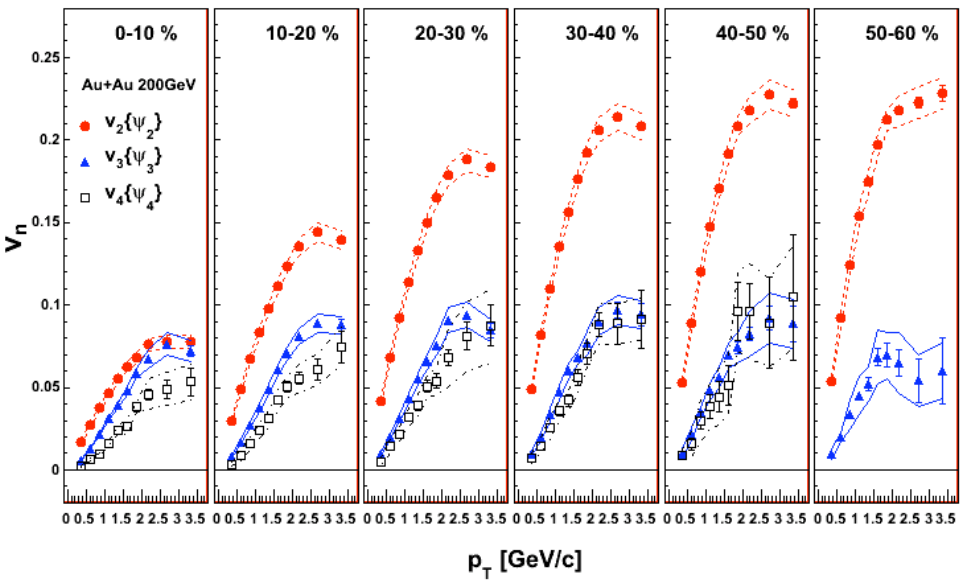

Figure 5. higher order event anisotropy as a function of p_T .

The centrality dependence of higher order event anisotropy is shown in figure 6 as a function of number of participant for two p_T slices, they are also compared with generalized eccentricity ε_n from initial geometry with a glauber model calculation. Since one would expect there will be additional effect from hydro-dynamic expansion, one can not really compare the magnitude between v_n and ε_n, however the relative difference between different harmonic orders could be taken in order to extract the effect from the expansion relative to the initial fluctuation.

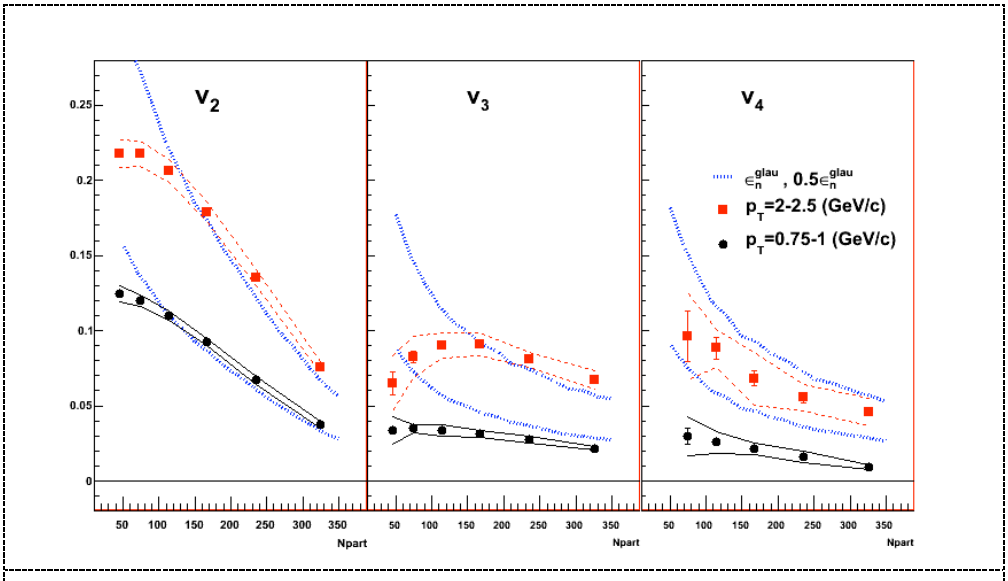

Figure 6. higher order event anisotropy as a function of number of participant

Figure 7 shows the v_3 measured with Φ_3 from the forward rapidity compared with v_3 from the two particle correlation methods, which shows slightly larger v_3 because of the possible non-flow contribution from jets at higher p_T, however the agreement at lower p_T between two experimental measurements as well as the agreement between hydro-dynamic calculation [3] and experimental data are remarkable.

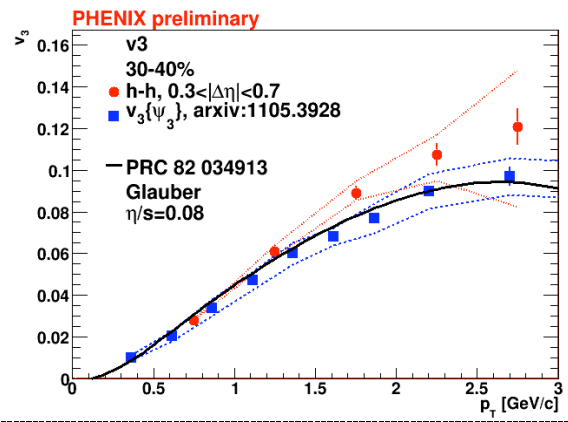

Figure 7. v_3 extracted with different methods compared with hydro-dynamic calculation

4. Summary

Higher order event anisotropy has been measured with higher order event plane defined at forward rapidity detectors and compared with two particle correlation method with various rapidity gap in 200GeV Au+Au colliaions at RHIC-PHENIX experiment. The results are compared with generalized initial geometrical eccentricity and with hydro-dynamic calculations. Higher order event anisotropy seems to be dominantly given by the initial geometrical fluctuation followed by the hydro-dynamic expansion.

References

[1] B. Alver and G. Roland, Phys. Rev. C81, 054905 (2010)
[2] arXiv:1105.3928
[3] B. Alver et al., Phys. Rev. C82, 034913 (2010)